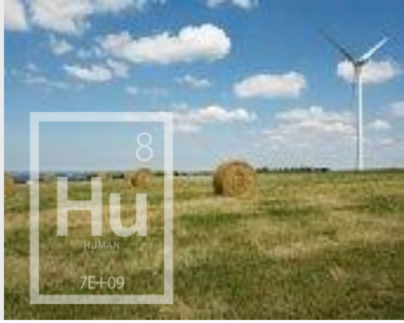
The Principles of Sustainable Chemistry and Engineering, A Pragmatic Approach

Science for a Sustainable World

Our Definition of Sustainability



Sustainability requires making every decision with the future in mind.

It is our relationship with the world around us – creating economic prosperity and social value while contributing to the protection of our planet.

Sustainable Chemistry and Engineering

Sustainable chemistry and engineering is a “cradle-to-cradle” concept that drives us to use resources more efficiently to:

- Minimize our footprint;
- Drive toward inherently safer processes and materials;
- Provide value and solutions to our customers and stakeholders;
- And, enhance the quality of life of current and future generations.

A History of Commitment to Sustainability

HH Dow partners with Westinghouse to develop Co-Generation

First industrial use of bacteria to degrade phenolic waste

Corporate Environmental Advisory Council formed

2005 Goals saved company $5 billion on $1 Billion Investment, 2015 Sustainability Goals Set

Dow wins 6th Presidential Green Chemistry award – more than any company

2005 Goals Set

1897 1906 1935 1953 1967 1986 1991 1996 2005 2007 2008 ***2015***

Dow Signs UN Global Compact

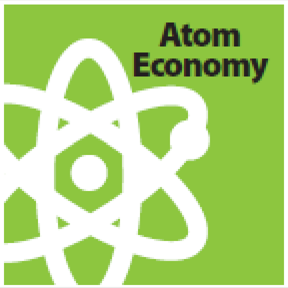
Dow's Frank Popoff pens Eco-Efficiency: *The Business Link to Sustainable Development*

Dow's Claude Fussler writes: *Driving Eco Innovation*

Waste Reduction Always Pays (WRAP) launched

"War on BTUs" energy conservation program launched

Developed water-based, acrylic technology that revolutionized the paint industry

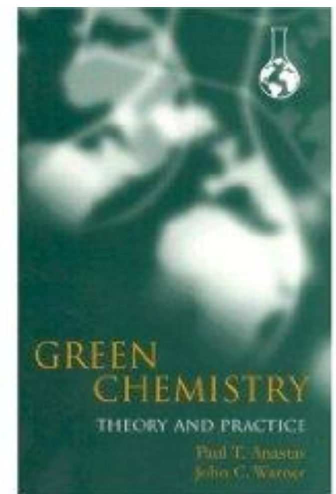


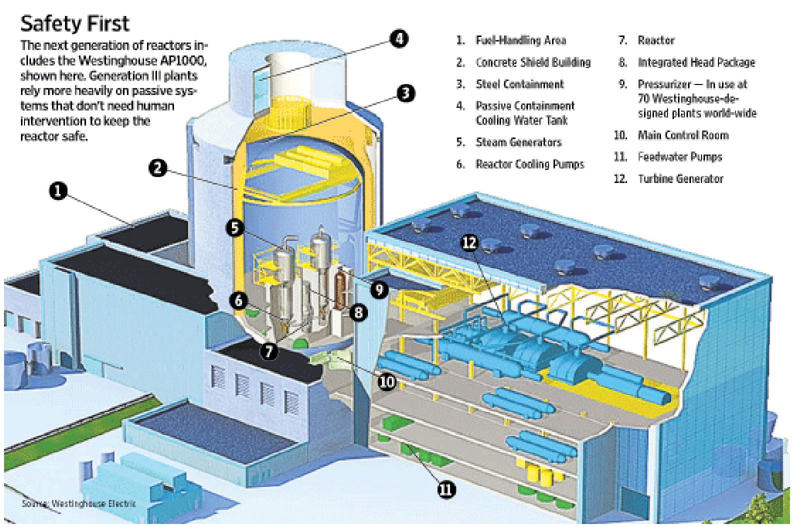
The
Principles of
Sustainable Chemistry and Engineering

. . . how we practice it at
The Dow Chemical Company,
sustaining it in our DNA!

Green Chemistry and Green Engineering

“design of products and processes that minimize the use and generation of hazardous substances” *US EPA*





GREEN ENGINEERING

Sandestin Conference;

Anastas and Zimmerman

The 12 Principles of Green Chemistry
- Anastas, Warner

1. **Prevention:** It is better to prevent waste than to treat or clean up waste after it has been created.

2. **Atom Economy**: Synthetic methods should be designed to maximize the incorporation of all materials used in the process into the final product.

3. **Less Hazardous Chemical Syntheses:** Wherever practicable, synthetic methods should be designed to use and generate substances that possess little or no toxicity to human health and the environment.

4. **Designing Safer Chemicals:** Chemical products should be designed to effect their desired function while minimizing their toxicity.

5. **Safer Solvents and Auxiliaries:** The use of auxiliary substances (e.g., solvents, separation agents, etc.) should be made unnecessary wherever possible and innocuous when used.

6. **Design for Energy Efficiency:** Energy requirements of chemical processes should be recognized for their environmental and economic impacts and should be minimized. If possible, synthetic methods should be conducted at ambient temperature and pressure.

7. **Use of Renewable Feedstocks:** A raw material or feedstock should be renewable rather than depleting whenever technically and economically practicable.

8. **Reduce Derivatives:** Unnecessary derivatization (use of blocking groups, protection/ deprotection, temporary modification of physical/chemical processes) should be minimized or avoided if possible, because such steps require additional reagents and can generate waste.

9. **Catalysis:** Catalytic reagents (as selective as possible) are superior to stoichiometric reagents.

10. **Design for Degradation:** Chemical products should be designed so that at the end of their function they break down into innocuous degradation products and do not persist in the environment.

11. **Real-time analysis for Pollution Prevention:** Analytical methodologies need to be further developed to allow for real-time, in-process monitoring and control prior to the formation of hazardous substances.

12. **Inherently Safer Chemistry for Accident Prevention:** Substances and the form of a substance used in a chemical process should be chosen to minimize the potential for chemical accidents, including releases, explosions, and fires.

The 12 Principles of Green Engineering
-- Anastas, Zimmerman

1. Inherent Rather Than Circumstantial: Designers need to strive to ensure that all materials and energy inputs and outputs are as inherently nonhazardous as possible.

2. Prevention Instead of Treatment: It is better to prevent waste than to treat or clean up waste after it is formed.

3. Design for Separation: Separation and purification operations should be designed to minimize energy consumption and materials use.

4. Maximize Efficiency: Products, processes, and systems should be designed to maximize mass, energy, space, and time efficiency.

5. Output-Pulled Versus Input-Pushed: Products, processes, and systems should be "output pulled" rather than "input pushed" through the use of energy and materials.

6. Conserve Complexity: Embedded entropy and complexity must be viewed as an investment when making design choices on recycle, reuse, or beneficial disposition.

7. Durability Rather Than Immortality: Targeted durability, not immortality, should be a design goal.

8. Meet Need, Minimize Excess: Design for unnecessary capacity or capability (e.g., "one size fits all") solutions should be considered a design flaw.

9. Minimize Material Diversity: Material diversity in multi-component products should be minimized to promote disassembly and value retention.

10. Integrate Material and Energy Flows: Design of products, processes, and systems must include integration and interconnectivity with available energy and materials flows.

11. Design for Commercial "Afterlife": Products, processes, and systems should be designed for performance in a commercial "afterlife."

12. Renewable Rather Than Depleting: Material and energy inputs should be renewable rather than depleting.

The 9 Principles of Green Engineering
-- Sandestin Conference

1. Engineer processes and products holistically, use systems analysis, and integrate environmental impact assessment tools.
2. Conserve and improve natural ecosystems while protecting human health and well-being.
3. Use life-cycle thinking in all engineering activities.
4. Ensure that all material and energy inputs and outputs are as inherently safe and benign as possible.
5. Minimize depletion of natural resources.
6. Strive to prevent waste.
7. Develop and apply engineering solutions, while being cognizant of local geography, aspirations, and cultures.
8. Create engineering solutions beyond current or dominant technologies; improve, innovate, and invent (technologies) to achieve sustainability.
9. Actively engage communities and stakeholders in development of engineering solutions

The Principles – Simplified

Color Key

Economic driver

Personal safety driver

Feedstock

Product properties that some customers and stakeholders value highly

12 Principles of Green Chemistry

1. Prevention
2. Atom Economy
3. Less Hazardous Chemical Syntheses
4. Designing Safer Chemicals
5. Safer Solvents and Auxiliaries
6. Design for Energy Efficiency
7. Use of Renewable Feedstocks
8. Reduce Derivatives
9. Catalysis
10. Design for Degradation
11. Real-time analysis for Pollution Prevention
12. Inherently Safer Chemistry for Accident Prevention

12 Principles of Green Engineering

1. Inherent Rather Than Circumstantial
2. Prevention Instead of Treatment
3. Design for Separation
4. Maximize Efficiency
5. Output-Pulled Versus Input-Pushed
6. Conserve Complexity
7. Durability Rather Than Immortality
8. Meet Need, Minimize Excess
9. Minimize Material Diversity
10. Integrate Material and Energy Flows
11. Design for Commercial "Afterlife"
12. Renewable Rather Than Depleting

Sandestin Conference: Principles of Green Engineering

1. **Engineer processes and products holistically, use systems analysis, and integrate environmental impact assessment tools.**
2. **Conserve and improve natural ecosystems while protecting human health and well-being.**
3. **Use life-cycle thinking in all engineering activities.**
4. **Ensure that all material and energy inputs and outputs are as inherently safe and benign as possible.**
5. **Minimize depletion of natural resources.**
6. **Strive to prevent waste.**
7. **Develop and apply engineering solutions, while being cognizant of local geography, aspirations, and cultures.**
8. **Create engineering solutions beyond current or dominant technologies; improve, innovate, and invent (technologies) to achieve sustainability.**
9. **Actively engage communities and stakeholders in development of engineering solutions.**

All those principles . . . Simplified:

The Four Themes of the Principles of Sustainable Chemistry and Engineering at Dow

12 Principles of Green Chemistry

1. Prevention
2. Atom Economy
3. Less Hazardous Chemical Syntheses
4. Designing Safer Chemicals
5. Safer Solvents and Auxiliaries
6. Design for Energy Efficiency
7. Use of Renewable Feedstocks
8. Reduce Derivatives

for Degradation

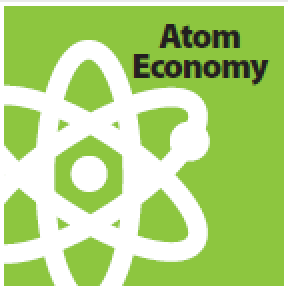
me analysis for Pollution Prevention

ntly Safer Chemistry for Accident Prevention

12 Principles of Gr

1. Inherent Rather T
2. Prevention Instea
3. Design for Separ
4. Maximize Efficie
5. Output-Pulled Ve
6. Conserve Compl
7. Durability Rather Than Immortality
8. Meet Need, Minimize Excess
9. Minimize Material Diversity
10. Integrate Material and Energy Flows
11. Design for Commercial "Afterlife"
12. Renewable Rather Than Depleting

Atom Economy



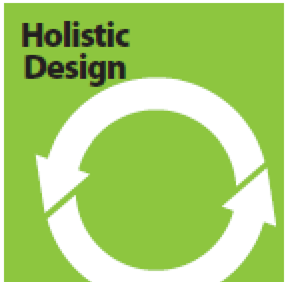
Reduced Hazard

tin Conference: Principles of Green Engineering

Energy Footprint

1. Engineer processes and products holistically, use systems analysis, and integrate enviro assessment tools.
2. Conserve and improve natural ecosystems while protecting human health and well-being
3. Use life-cycle thinking in all engineering activities.
4. Ensure that all material and energy inputs and outputs are as inherently safe and benign
5. Minimize depletion of natural re
6. Strive to prevent waste.
7. Develop and apply engineering solut izant of local geography, aspi cultures.
8. Create engineering solutions beyond echnologies; improve, innovate, and invent (technologies) to achieve sustainabili
9. Actively engage communities and sta nent of engineering solutions.

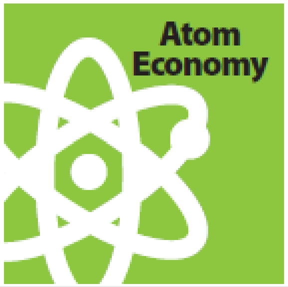
Holistic Design



Atom Economy

$$\frac{mass\ of\ atoms\ utilized}{mass\ of\ all\ reactant\ atoms} x100\%$$

Prof. Barry Trost coined the concept of atom economy for total synthesis in the 1980s. The term describes reducing the use of nonrenewable resources, minimizing the amount of waste, and reducing the number of steps used to synthesize chemicals. Atom economy is one of the fundamental cornerstones of green chemistry, and is a concept widely used by those who are working to improve the efficiency of chemical reactions.



12 Principles of Green Chemistry

1. Prevention
2. Atom Economy
3. Less Hazardous Chemical Syntheses
4. Designing Safer Chemicals
5. Safer Solvents and Auxiliaries
6. Design for Energy Efficiency
7. Use of Renewable Feedstocks
8. Reduce Derivatives
9. Catalysis
10. Design for Degradation
11. Real-time analysis for Pollution Prevention
12. Inherently Safer Chemistry for Accident Prevention

12 Principles of Green Engineering

1. Inherent Rather Than Circumstantial
2. Prevention Instead of Treatment
3. Design for Separation
4. Maximize Efficiency
5. Output-Pulled Versus Input-Pushed
6. Conserve Complexity
7. Durability Rather Than Immortality
8. Meet Need, Minimize Excess
9. Minimize Material Diversity
10. Integrate Material and Energy Flows
11. Design for Commercial "Afterlife”
12. Renewable Rather Than Depleting

Sandestin Conference: Principles of Green Engineering

1. Engineer processes and products holistically, use systems analysis, and integrate environmental impact assessment tools.
2. Conserve and improve natural ecosystems while protecting human health and well-being.
3. Use life-cycle thinking in all engineering activities.
4. Ensure that all material and energy inputs and outputs are as inherently safe and benign as possible.
5. Minimize depletion of natural resources.
6. Strive to prevent waste.
7. Develop and apply engineering solutions, while being cognizant of local geography, aspirations, and cultures.
8. Create engineering solutions beyond current or dominant technologies; improve, innovate, and invent (technologies) to achieve sustainability.
9. Actively engage communities and stakeholders in development of engineering solutions.

Dow Case Study

Atom Economy

INNOVATIVE PROPYLENE OXIDE PROCESS

Atom Economy

Reduce Hazard

Energy

Description

Dow and BASF jointly developed the hydrogen peroxide to propylene oxide (HPPO) technology, which significantly reduces waste water, energy and capital over competing technologies.

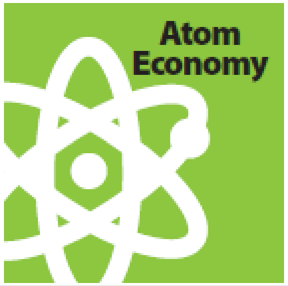
Sustainability Profile

- Uses hydrogen peroxide and propylene as raw materials
- Produces only propylene oxide and water
- Waste water reduced by 70% to 80%
- Energy use reduced by 35%
- Reduced physical footprint requires up to 25% less capital
- Avoids need for co-product infrastructure and markets

AWARD WINNER
U.S. Presidential Green Chemistry Challenge
"Greener Synthetic Pathways"

Smart Solutions - Innovations for Tomorrow - Responsible Operations - Partners for Change

Dow Case Study



Atom Economy

Energy

Advanced Batteries

DOW KOKAM
Power to move the world

Description

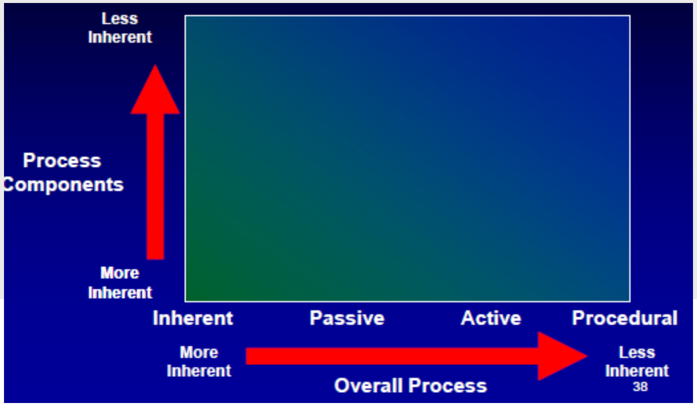
Dow Kokam was established in 2009 to develop and manufacture technologically advanced and economically viable battery solutions for the transportation, defense, industrial and medical industries.

Sustainability Profile

- Extended run time
- More than 10 years of operational life
- Ability to perform well in a wide range of temperatures
- Reduces need for complex cooling systems
- Higher depth of discharge (greater than 80% in production EV)
- State-of-the-art production facility in Midland, Michigan

Smart Solutions - Innovations for Tomorrow - Responsible Operations - Partners for Change

Reduced Hazard



Inherently Safer – The Designs of the Future, Hendershot and Kletz, 2010.

An inherently safer design is one that avoids hazards instead of controlling them, particularly by reducing the amount of hazardous material and the number of hazardous operations in the plant.

- Process Safety Strategies, in general order of robustness and reliability: Inherent, Passive, Active, Procedural
- "Inherent" by: Minimize, Substitute, Moderate, Simplify

12 Principles of Green Chemistry

1. Prevention
2. Atom Economy
3. **Less Hazardous Chemical Syntheses**
4. **Designing Safer Chemicals**
5. **Safer Solvents and Auxiliaries**
6. Design for Energy Efficiency
7. Use of Renewable Feedstocks
8. Reduce Derivatives
9. Catalysis
10. Design for Degradation
11. Real-time analysis for Pollution Prevention
12. **Inherently Safer Chemistry for Accident Prevention**

12 Principles of Green Engineering

1. **Inherent Rather Than Circumstantial**
2. Prevention Instead of Treatment
3. Design for Separation
4. Maximize Efficiency
5. Output-Pulled Versus Input-Pushed
6. Conserve Complexity
7. **Durability Rather Than Immortality**
8. Meet Need, Minimize Excess
9. Minimize Material Diversity
10. Integrate Material and Energy Flows
11. Design for Commercial "Afterlife"
12. Renewable Rather Than Depleting

Sandestin Conference: Principles of Green Engineering

1. Engineer processes and products holistically, use systems analysis, and integrate environmental impact assessment tools.
2. Conserve and improve natural ecosystems **while protecting human health and well-being.**
3. Use life-cycle thinking in all engineering activities.
4. **Ensure that all material and energy inputs and outputs are as inherently safe and benign as possible.**
5. Minimize depletion of natural resources.
6. Strive to prevent waste.
7. Develop and apply engineering solutions, while being cognizant of local geography, aspirations, and cultures.
8. Create engineering solutions beyond current or dominant technologies; improve, innovate, and invent (technologies) to achieve sustainability.
9. Actively engage communities and stakeholders in development of engineering solutions.

Dow Case Study

Reduce Hazards

Atom Economy

Reduce Hazard

SENTRICON® TERMITE COLONY ELIMINATION SYSTEM

Description

Millions of home and commercial building owners around the world depend on innovative Dow technology in SENTRICON bait systems to protect from costly insect damage.

Sustainability Profile

- Highly specific bait eliminates entire colonies, using one ten thousandth the amount of product traditionally applied
- Monitor-Bait-Eliminate model for termite elimination and continued protection
- Bait was first to be registered under the U.S. EPA's Reduced Risk Pesticide Initiative.
- Protecting the White House, the Statue of Liberty, the Alamo, the senate building in Italy and a Buddhist temple in Japan

2000
AWARD WINNER
U.S. Presidential Green Chemistry Challenge
"Greener Synthetic Pathways"

Dow AgroSciences

Smart Solutions - Innovations for Tomorrow - Responsible Operations - Partners for Change

Dow Case Study

Reduce Hazards

CO_2 CAPTURE

ALSTOM

Description

Pilot plant uses proprietary advanced-amine technology jointly developed by Dow and Alstom to capture carbon dioxide from new or existing industrial facilities.

Atom Economy

Reduce Hazard

Energy

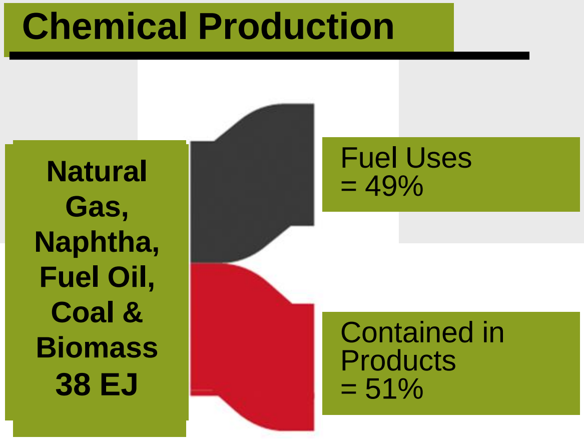
Holistic Design

Sustainability Profile

- Carbon capture and sequestration reduces GHG emissions from coal combustion – which represents 40% of world's power generation
- Dow and Alstom's Advanced Amine Process leads the industry in carbon capture
- Pilot plant in West Virginia designed to capture 1,800 tons/year of CO_2
- Large-scale facility in Poland being constructed to capture 1.8 million tons/year of CO_2

Smart Solutions - Innovations for Tomorrow - Responsible Operations - Partners for Change

Energy Footprint



EIA 2004 Refining Data and IEA Energy Technology Transitions for Industry 2009.

Chemistry and chemical transformations must and do play a major role in capturing and converting substances into energy as well as converting existing sources of energy into a form that is usable to society.

Green Chemistry Theory and Practice, Anastas and Warner, 1998.

Energy Footprint

12 Principles of Green Chemistry

1. Prevention
2. Atom Economy
3. Less Hazardous Chemical Syntheses
4. Designing Safer Chemicals
5. Safer Solvents and Auxiliaries
6. **Design for Energy Efficiency**
7. Use of Renewable Feedstocks
8. Reduce Derivatives
9. Catalysis
10. Design for Degradation
11. Real-time analysis for Pollution Prevention
12. Inherently Safer Chemistry for Accident Prevention

12 Principles of Green Engineering

1. Inherent Rather Than Circumstantial
2. Prevention Instead of Treatment
3. **Design for Separation**
4. Maximize Efficiency
5. Output-Pulled Versus Input-Pushed
6. Conserve Complexity
7. Durability Rather Than Immortality
8. Meet Need, Minimize Excess
9. Minimize Material Diversity
10. **Integrate Material and Energy Flows**
11. Design for Commercial "Afterlife"
12. Renewable Rather Than Depleting

Sandestin Conference: Principles of Green Engineering

1. Engineer processes and products holistically, use systems analysis, and integrate environmental impact assessment tools.
2. Conserve and improve natural ecosystems while protecting human health and well-being.
3. Use life-cycle thinking in all engineering activities.
4. Ensure that all material and energy inputs and outputs are as inherently safe and benign as possible.
5. **Minimize depletion of natural resources.**
6. Strive to prevent waste.
7. Develop and apply engineering solutions, while being cognizant of local geography, aspirations, and cultures.
8. **Create engineering solutions beyond current or dominant technologies; improve, innovate, and invent (technologies) to achieve sustainability.**
9. Actively engage communities and stakeholders in development of engineering solutions.

Energy Efficiency – Dow Processes

Energy Footprint

Dow Case Studies

Energy Footprint

Net-Zero Energy Home

Energy

Description

Michigan's first affordable net-zero energy home jointly built by Dow and Cobblestone Homes – utilizing readily available energy efficiency technologies from Dow.

Sustainability Profile

- Uses 60-70 percent less energy than conventional homes
- Saves $3,500 in annual energy costs
- Saves more energy than it consumes – averting over 44,000 lbs of CO_2 annually
- Features Dow products and solutions:
  - POWERHOUSE™ solar shingles
  - STYROFOAM™ brand insulation and air-sealing products
  - DOWFROST™ heat transfer fluid
  - Also products made with Dow polyurethanes, plastics, binders and fibers

DOW™ POWERHOUSE™ Roof Shingles

Atom Economy

Energy

Description

Building integrated photovoltaic (BIPV) design combines roofing protection and power generation in one product.

Sustainability Profile

- Aesthetically pleasing and neighborhood-friendly, it's the best looking solar option available for asphalt rooftops
- Installed by a roofer along with standard asphalt roofing materials which eliminates additional steps and costs
- Interconnected system design allows for a single power connection
- Launched in October 2009, the POWERHOUSE™ Solar Shingle is expected to be commercially available in 2011

TIME Magazine: "50 Best Inventions of 2009"

2010 AWARD WINNER GLOBE Foundation "Environmental Excellence in Emerging Technology"

Smart Solutions - Innovations for Tomorrow - Responsible Operations - Partners for Change

Advanced Batteries

DOW KOKAM Power to move the world

Atom Economy

Energy

Description

Dow Kokam was established in 2009 to develop and manufacture technologically advanced and economically viable battery solutions for the transportation, defense, industrial and medical industries.

Sustainability Profile

- Extended run time
- More than 10 years of operational life
- Ability to perform well in a wide range of temperatures
- Reduces need for complex cooling systems
- Higher depth of discharge (greater than 80% in production EV)
- State-of-the-art production facility in Midland, Michigan

Smart Solutions - Innovations for Tomorrow - Responsible Operations - Partners for Change

Cradle to Cradle: Holistic Design

With our growing knowledge of the living earth, design can reflect a new spirit. In fact, when designers employ the intelligence of natural systems—the effectiveness of nutrient cycling, the abundance of the sun's energy—they can create products, industrial systems, buildings, even regional plans that allow nature and commerce to fruitfully co-exist.

Cradle to Cradle, McDonough & Braungart, 2002.

12 Principles of Green Chemistry

1. Prevention
2. Atom Economy
3. Less Hazardous Chemical Syntheses
4. Designing Safer Chemicals
5. Safer Solvents and Auxiliaries
6. Design for Energy Efficiency
7. **Use of Renewable Feedstocks**
8. Reduce Derivatives
9. Catalysis
10. **Design for Degradation**
11. Real-time analysis for Pollution Prevention
12. Inherently Safer Chemistry for Accident Prevention

12 Principles of Green Engineering

1. Inherent Rather Than Circumstantial
2. Prevention Instead of Treatment
3. Design for Separation
4. Maximize Efficiency
5. Output-Pulled Versus Input-Pushed
6. **Conserve Complexity**
7. Durability Rather Than Immortality
8. **Meet Need, Minimize Excess**
9. **Minimize Material Diversity**
10. Integrate Material and Energy Flows
11. **Design for Commercial "Afterlife"**
12. **Renewable Rather Than Depleting**

Sandestin Conference: Principles of Green Engineering

1. **Engineer processes and products holistically, use systems analysis, and integrate environmental impact assessment tools.**
2. **Conserve and improve natural ecosystems** while protecting human health and well-being.
3. **Use life-cycle thinking in all engineering activities.**
4. Ensure that all material and energy inputs and outputs are as inherently safe and benign as possible.
5. **Minimize depletion of natural resources.**
6. Strive to prevent waste.
7. **Develop and apply engineering solutions, while being cognizant of local geography, aspirations, and cultures.**
8. Create engineering solutions beyond current or dominant technologies; improve, innovate, and invent (technologies) to achieve sustainability.
9. **Actively engage communities and stakeholders in development of engineering solutions.**

Dow Case Study

The Sustainable Story of Plastic Packaging

Description

Light weight, durable, and flexible – the protective properties of plastic make it one of the world's most sustainable performers in delivering environmental, economic and social value.

Sustainability Profile

Atom Economy

Reduce Hazard

Energy

Holistic Design

- **Flexible packaging reduces materials –** 2 lbs of plastic deliver the same amount of liquid as 3 lbs aluminum, 8 lbs steel, or 27 pounds glass
- **Plastic saves energy –** 7 trucks deliver the same number of paper bags that 1 truck of plastic bags can carry
- **Plastic reduces harmful emissions –** Organic waste in landfills emit methane: a GHG with 23 times more global warming potential than CO_2 and plastic packaging helps keep food out of the landfill
- **Plastic saves resources –** By preventing food from spoiling and protecting consumer goods from damage during distribution

Smart Solutions - Innovations for Tomorrow - Responsible Operations - Partners for Change

Incorporating Sustainability into the Business Units

Vision for the Company

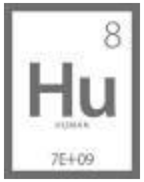
- Drive sustainability into decision making process
- Instill life cycle thinking throughout the company
- Like safety, make sustainability a part of everyday thinking
- Recognized externally as a leader in sustainability
- Motivated employee base

The Principles of Sustainable Chemistry and Engineering at Dow

THE PROGRAM – Driving Sustainability into our DNA

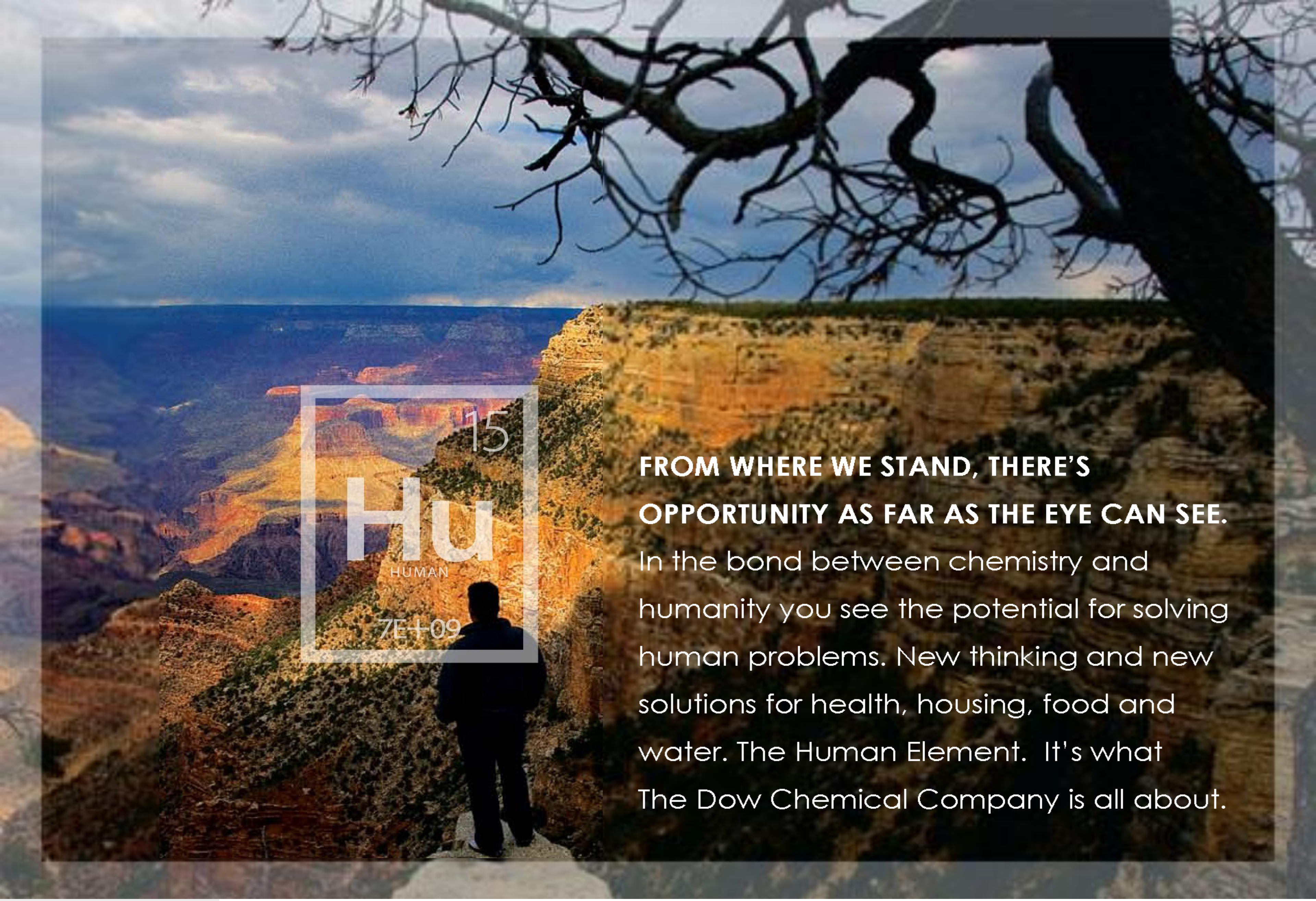
Deliver to the R&D community (and other functions as desired), a slate of content tailored to the users' needs:

- Overview of the Principles of Sustainable Chemistry and Engineering (everyone)
- Module 1: An Introduction to the Principles of Sustainable Chemistry and Engineering
- Module 2 Workshop: "Reduced Hazard: Toxicology and Environmental Impact 101"
- Module 3 Workshop: "Holistic Design"
- Module 4 Workshop: "Case Studies for the Themes"
- Module 5: "Showcase" forum for participants' projects, applying the principles



Externally:

- Strategic Universities – recruiting material
- Curriculum/STEM Outreach


15
Hu
HUMAN
7E+09
FROM WHERE WE STAND, THERE'S OPPORTUNITY AS FAR AS THE EYE CAN SEE.
In the bond between chemistry and humanity you see the potential for solving human problems. New thinking and new solutions for health, housing, food and water. The Human Element. It's what The Dow Chemical Company is all about.